(12) UK Patent Application (19) GB (11) 2 333 159 (13) A

(43) Date of A Publication 14.07.1999

(21) Application No 9900546.4

(22) Date of Filing 12.01.1999

(30) Priority Data
(31) 005927 (32) 12.01.1998 (33) US

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(51) INT CL^6
F02D 35/00

(52) UK CL (Edition Q)
G1N NAAJCR N3S1B N4E N7A1 N7C
F1B BBB BB102 BB140 BB200 BB206 BB210 BB212 BB236
U1S S1990

(56) Documents Cited
JP 010053032 A US 5205260 A

(58) Field of Search
UK CL (Edition Q) **F1B BBA BBB , G1N NAAJCR**
INT CL^6 **F02D**
Online: WPI, JAPIO

(54) Abstract Title
Method and system for estimating cylinder air flow

(57) A method and system for estimating the amount of air flow into an internal combustion engine utilises a combination of intake manifold pressure, engine and exhaust manifold temperatures and throttle position. Control logic determines a partial pressure of air in the intake manifold based on an EGR (exhaust gas recirculation) flow so as to minimise the effects of errors of the EGR and air flow estimates by placing greater emphasis on intake manifold pressure sensor information. Throttle position as sensed by a throttle position sensor is used to project the partial pressure of air several engine events ahead. This anticipated partial pressure of air allows the early estimation of air charge into the cylinder port to provide the fuel injection system sufficient time to dispense fuel.

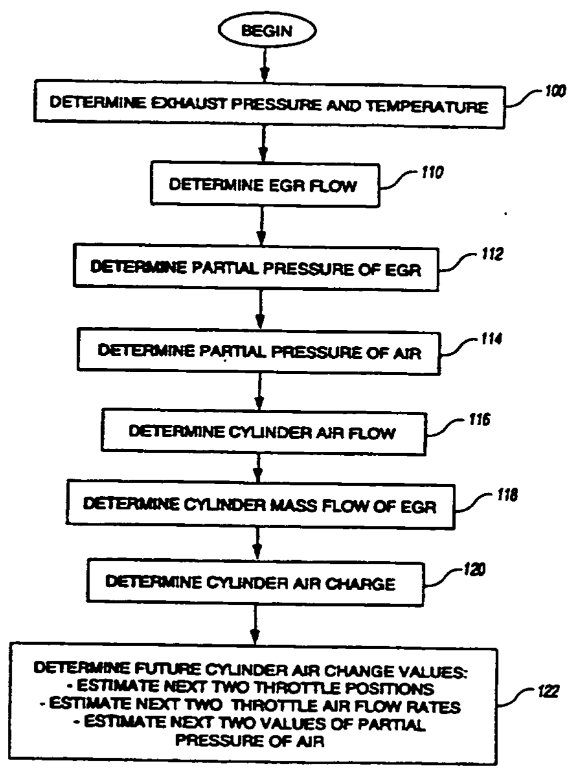

Fig. 2

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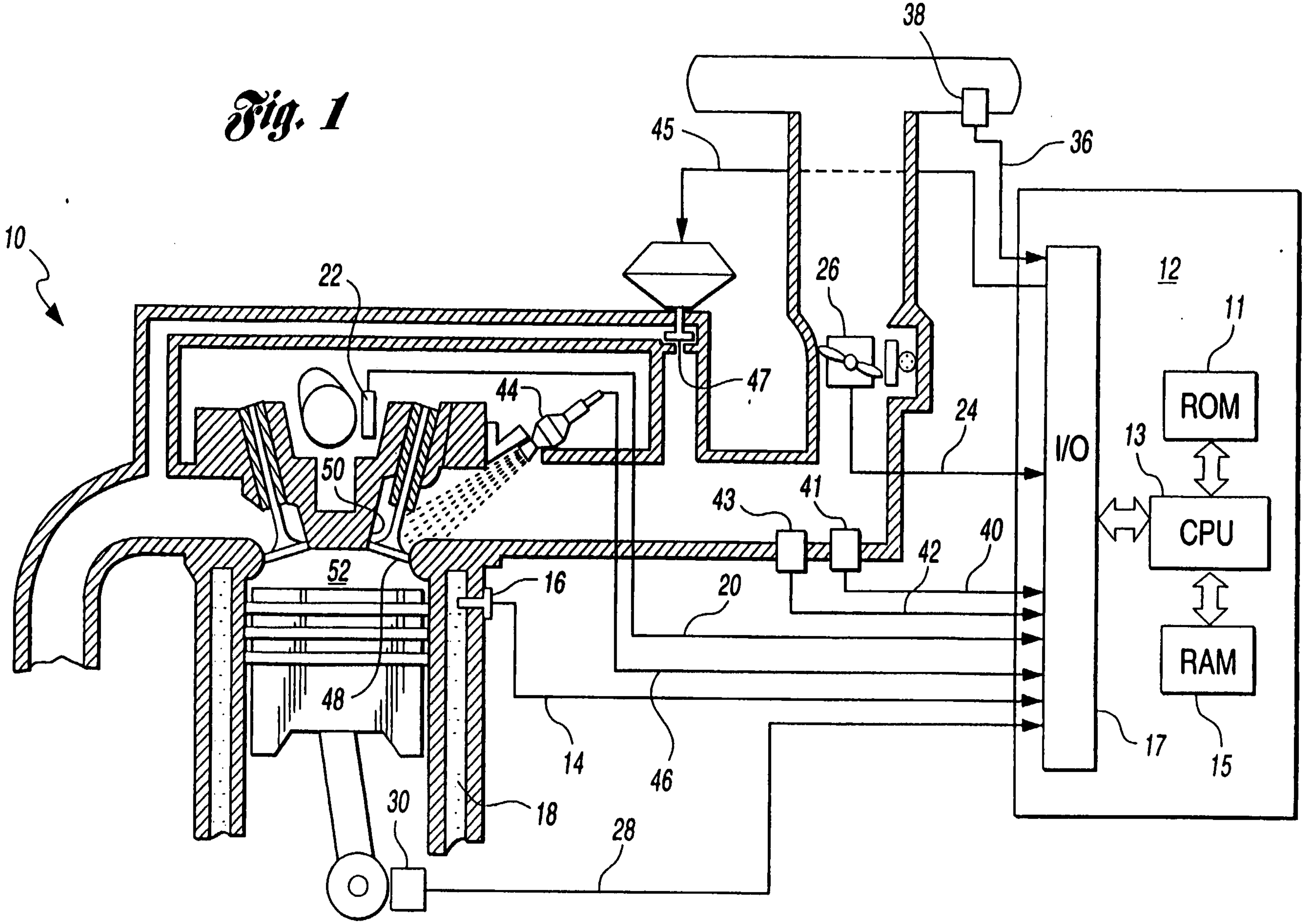
Fig. 1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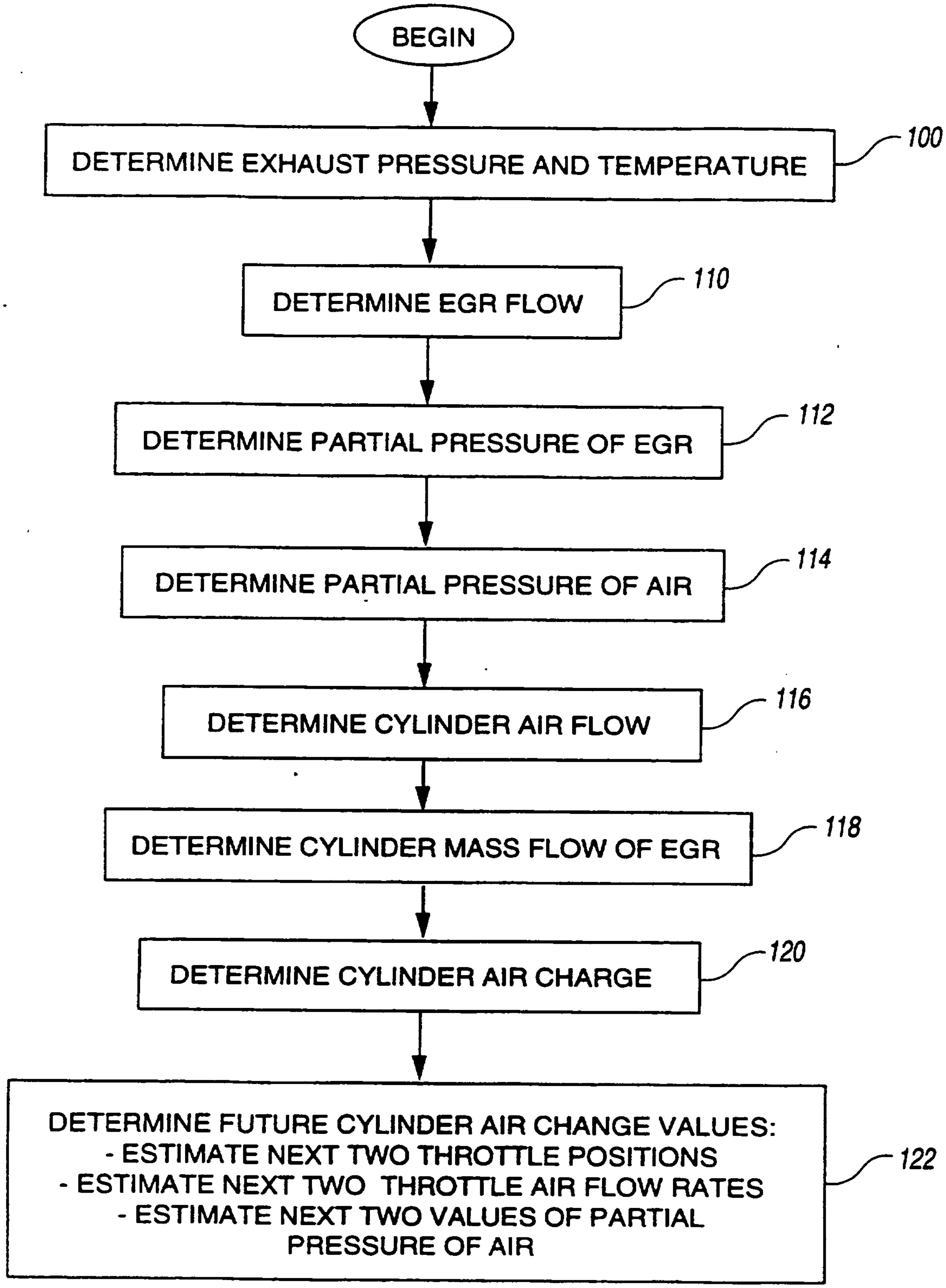
BEGIN
DETERMINE EXHAUST PRESSURE AND TEMPERATURE
100
DETERMINE EGR FLOW
110
DETERMINE PARTIAL PRESSURE OF EGR
112
DETERMINE PARTIAL PRESSURE OF AIR
114
DETERMINE CYLINDER AIR FLOW
116
DETERMINE CYLINDER MASS FLOW OF EGR
118
DETERMINE CYLINDER AIR CHARGE
120
DETERMINE FUTURE CYLINDER AIR CHANGE VALUES:
- ESTIMATE NEXT TWO THROTTLE POSITIONS
- ESTIMATE NEXT TWO THROTTLE AIR FLOW RATES
- ESTIMATE NEXT TWO VALUES OF PARTIAL PRESSURE OF AIR
122

Fig. 2

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METHOD AND SYSTEM FOR ESTIMATING CYLINDER AIR FLOW

This invention relates to methods and systems for estimating air flow into a cylinder of an internal combustion engine.

The mass of air, or cylinder air charge, inducted into each cylinder of an internal combustion engine must be known as precisely as possible in order to match the air mass with an appropriate mass of metered fuel. Placing sensors at the intake port of each cylinder is technically very difficult and expensive. Instead, a sensor is typically located either inside the intake manifold or at the throttle opening into the intake manifold. A physics model is then used to estimate the air mass propagation through the intake manifold into each cylinder.

Two types of the above described sensors are typically employed in internal combustion engines. One type is a manifold absolute pressure (MAP) sensor. An estimation algorithm treats the manifold pressure as an input to the system and uses mapped engine data and engine speed to estimate air flow into the engine cylinders. The other type of sensor is a relatively expensive mass air flow (MAF) sensor used to directly measure mass air flow at the throttle body.

For the MAF based system, fresh air from the throttle is directly measured. EGR gas content is left out of the cylinder port air charge estimation. Other air flows not from the throttle (via vacuum lines from the brakes, canister purge system, etc.) are not accounted for by the MAF measurement and must be accounted for by other means.

The MAP sensor measures the absolute pressure in the intake manifold and thus incorporates the air flow from all sources. Difficulties arise, however, when gases other than air are introduced into the intake manifold. For the MAP based system (often referred to as a speed density system), gases other than air, such as the deliberately introduced exhaust gas (referred to as EGR or exhaust gas

recirculation), increase the manifold pressure. These gases should not be matched by fuel. However, the MAP sensor cannot distinguish between fresh air and EGR. Thus, EGR mass in the intake manifold must be measured or estimated.

Thus, there exists a need for a MAP sensor-based system for estimating cylinder air charge in which an error in estimating EGR has a minimal impact on the estimation of the cylinder air charge.

It is thus a general object of the present invention to provide a simple and inexpensive method and system for estimating cylinder air flow.

According to the present invention, there is provided a method for determining air flow into a cylinder of an internal combustion engine having an intake manifold for receiving air to be inducted into the engine, an exhaust manifold for emitting exhaust gas combusted by the engine and an exhaust gas recirculation (EGR) orifice for recirculating a portion of the exhaust gas into the intake manifold, the method comprising: sensing a pressure of the intake manifold and generating a corresponding intake pressure signal; determining a pressure of the exhaust manifold and generating a corresponding exhaust pressure signal; determining an EGR flow through the EGR orifice based on the intake pressure signal and the exhaust pressure signal; determining a partial pressure of air based on the EGR flow and the intake pressure signal; and determining the air flow into the cylinder based on the partial pressure of air.

Further, according to the present invention there is provided a system for determining air flow into a cylinder of an internal combustion engine having an intake manifold for receiving air to be inducted into the engine, an exhaust manifold for emitting exhaust gas combusted by the engine and an exhaust gas recirculation (EGR) orifice for recirculating a portion of the exhaust gas into the intake manifold, the system comprising: an intake pressure sensor for sensing a pressure of the intake manifold and generating

a corresponding intake pressure signal; means for determining a pressure of the exhaust manifold and generating a corresponding exhaust pressure signal; and control logic operative to determine an EGR flow through the EGR orifice based on the intake pressure signal and the exhaust pressure signal, determine a partial pressure of air based on the EGR flow and the intake pressure signal, and determine the air flow into the cylinder based on the partial pressure of air.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of an internal combustion engine and an electronic engine controller which embody the principles of the present invention; and

Figure 2 is a flow diagram illustrating the general sequence of steps associated with the operation of the present invention.

Turning now to Figure 1, there is shown an internal combustion engine which incorporates the teachings of the present invention. The internal combustion engine 10 comprises a plurality of combustion chambers, or cylinders, one of which is shown in Figure 1. The engine 10 is controlled by an Electronic Control Unit (ECU) 12 having a Read Only Memory (ROM) 11, a Central Processing Unit (CPU) 13, and a Random Access Memory (RAM) 15. The ECU 12 receives a plurality of signals from the engine 10 via an Input/Output (I/O) port 17, including, but not limited to, an Engine Coolant Temperature (ECT) signal 14 from an engine coolant temperature sensor 16 which is exposed to engine coolant circulating through coolant sleeve 18, a Cylinder Identification (CID) signal 20 from a CID sensor 22, a throttle position signal 24 generated by a throttle position sensor 26 indicating the position of a throttle plate (not shown) operated by a driver, a Profile Ignition Pickup (PIP) signal 28 generated by a PIP sensor 30, an air intake

temperature signal 36 from an air temperature sensor 38, an intake manifold temperature signal 40 from an intake manifold temperature sensor 41, and an intake manifold pressure signal 42 from manifold absolute pressure (MAP) sensor 43.

The ECU 12 processes these signals and generates corresponding signals, such as a fuel injector pulse waveform signal transmitted to the fuel injector 44 on signal line 46 to control the amount of fuel delivered by the fuel injector 44. ECU 12 also generates an exhaust gas recirculation (EGR) signal 45 to control the opening of an EGR orifice 47 via actuator 49. Actuator 49 may be a stepper motor or a variable position solenoid. EGR orifice 47 is used to improve fuel economy as well as reduce the emission of nitrous oxides by cooling the combustion process.

Intake valve 48 operates to open and close intake port 50 to control the entry of the air/fuel mixture into combustion chamber 52.

Turning now to Figure 2, there is shown a flow diagram illustrating the general sequence of steps associated with the method of the present invention. Although the steps shown in Figure 2 are depicted sequentially, they can be implemented utilising interrupt-driven programming strategies, object-oriented programming, or the like. In a preferred embodiment, the steps shown in Figure 2 comprise a portion of a larger routine which performs other engine control functions.

The method begins with the step of determining an exhaust pressure and temperature, as shown at block 100. If pressure and temperature are not sensed directly in the exhaust manifold, these variables have to be estimated based on engine mapping data.

A simple method of estimating exhaust pressure and temperature is to make these variables a function of engine air flow (M_{cyl_air}). In the case of exhaust temperature, spark advance (spark_adv) (spark timing) also has a significant

effect. These variables are estimated according to the following:

$$P_{exh}(k) = Fn_{P_{exhaust}}\left(\dot{M}_{cyl\_air}(k-1),\ P_{amb}\right) \tag{1}$$

$$T_{exh}(k) = Fn_{T_{exhaust}}\left(\dot{M}_{cyl\_air}(k-1)\right) Fn_{T_{exhaust_{spk}}}(spark_{adv}(k)), \tag{2}$$

where $\dot{M}_{cyl\_air}(k-1)$ corresponds to a previously determined cylinder air flow rate according to this invention and P_{amb} represents barometric pressure measured from engine start and estimated during engine operation. More sophisticated methods of estimating these variables are possible, but are outside the scope of this disclosure.

Next, an EGR flow through the orifice 47 is determined, as shown at block 110, according to the following:

$$\dot{M}_{egr}(k) = \frac{P_{exh}(k)\sqrt{T_{exh_{nom}}}}{P_{exh_{nom}}\sqrt{T_{exh}(k)}} \cdot Fn_{egr_{flow\_char}}(egr_{step_{pos}}) Fn_{SubSonic}\left(\frac{P_m(k)}{P_{exh}(k)}\right) \tag{3}$$

where,

- $\dot{M}_{egr}(k)$ is the mass flow rate of EGR through the orifice 47;
- $P_{exh}(k)$ is the current measured or estimated exhaust pressure;
- P_{exh_nom} is the nominal exhaust pressure used to determine the EGR flow characteristic on the stand;
- T_{exh_nom} is the nominal exhaust temperature used to determine the EGR flow characteristic on the stand;
- $T_{exh}(k)$ is the current measured or estimated exhaust temperature;
- $P_m(k)$ is the measured intake manifold pressure via MAP 43;

FN_egr_flow_char(egr_step_pos) is the sonic EGR flow function for the orifice opening when the absolute pressure ratio is greater than .528. This mapped data incorporates many aspects of orifice flow into one lumped non-linear function based on the position of the stepper motor or solenoid; and

$$Fn_{SubSonic}\left(\frac{P_m(k)}{P_{exh}(k)}\right)$$

is the sub-sonic flow correction factor when the absolute pressure ratio is less than .528:

$$FnSubSonic = \begin{Bmatrix} \dfrac{\sqrt{\dfrac{2\gamma}{\gamma-1}\left[\left(\dfrac{P_m}{P_{amb}}\right)^{\frac{2}{\gamma}} - \left(\dfrac{P_m}{P_{amb}}\right)^{\frac{\gamma+1}{\gamma}}\right]}}{}_{if\, \frac{P_m}{P_{amb}}} \geq \left(\dfrac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} \\ \\ \dfrac{\sqrt{\dfrac{2\gamma}{\gamma-1}\left[\left(\dfrac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}} - \left(\dfrac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}\right]}}{}_{if\, \frac{P_m}{P_{amb}}} < \left(\dfrac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} \end{Bmatrix} \quad (4)$$

where γ for air is 1.399 (γ for EGR is about the same).

Simplifying:

$$FnSubSonic = \begin{Bmatrix} \sqrt{7.01253\left[\left(\dfrac{P_m}{P_{amb}}\right)^{1.42959} - \left(\dfrac{P_m}{P_{amb}}\right)^{1.7148}\right]}_{if\, \frac{P_m}{P_{amb}}} \geq 0.52845 \\ \\ 0.68454_{if\, \frac{P_m}{P_{amb}}} < 0.52845 \end{Bmatrix} \quad \textbf{(5)}$$

The partial pressure of EGR is determined next, as shown at block 112, indicating the fraction of total pressure attributed to EGR. The partial pressure of EGR in the intake manifold is estimated based on the state equation

of the ideal gas law. Differentiating the ideal gas law expression:

$$P_{EGR} = \frac{M_{EGR} R T_m}{V_m} \tag{6}$$

results in a differential equation for the partial pressure of EGR in the intake manifold:

$$\dot{P}_{EGR} = \frac{R T_m}{V_m}\left(\dot{M}_{EGR} - \frac{P_{EGR}}{P_m}\dot{M}_{cyl}\right) + \frac{P_{EGR}}{T_m}\dot{T}_m \tag{7}$$

$\dot{M}_{cyl}$ is replaced with the cylinder pumping rate equation:

$$fn_{eng_{temp}}(T_m, T_{eng})\left(\alpha_1(N(k))\,P_m(k) + \alpha_2(N(k))\frac{P_{amb}(i)}{P_{amb_{nom}}}\right) \tag{8}$$

where $\alpha_1(N(k))$ and $\alpha_2(N(k))$, representative of the slope, α_1, and offset, α_2, for engine pumping, which vary as engine speed, N, changes, are obtained from engine mapping data. fn_eng_temp(T_m, T_{eng}) is a function that accounts for the engine pumping rate change when the intake manifold and engine coolant temperature no longer match the nominal mapped conditions.

A difference equation is then obtained using Euler integration:

$$\frac{P_{EGR}(k) - P_{EGR}(k-1)}{\Delta t} = \frac{R T_m(k)}{V_m}$$

$$\left(\dot{M}_{EGR}(k) - \frac{P_{EGR}(k)}{P_m(k)} fn_{eng_{temp}}(T_m, T_{eng})\left[\alpha_1(N(k))\,P_m(k) + \alpha_2(N(k))\frac{P_{amb}(i)}{P_{amb_{nom}}}\right]\right) \tag{9}$$

$$+ \frac{P_{EGR}(k)}{T_m(k)}\,\frac{T_m(k) - T_m(k-1)}{\Delta t}$$

Solving for $P_{EGR}(k)$:

$$P_{EGR}(k) = \frac{P_{EGR}(k-1) + \Delta t \frac{RT_m(k)}{V_m} \dot{M}_{EGR}(k)}{\Delta t \frac{RT_m(k)}{V_m} fn_{eng_{temp}}(T_m, T_{eng}) \left(\alpha_1(N(k)) + \alpha_2(N(k)) \frac{P_{amb}(i)}{P_m(k)\, P_{amb_{nom}}} \right) + \frac{T_m(k-1)}{T_m(k)}}, \tag{10}$$

where,

$P_{EGR}(k)$	is the present estimate of the partial pressure of EGR in the intake manifold;
$P_{EGR}(k-1)$	is the previous estimate of P_{EGR};
Δt	is the time between updates of this algorithm;
$RT_m(k)/V_m$	stands for the ideal gas law coefficient based on the ideal gas constant for EGR (practically the same as air), the present temperature of the intake manifold, and the volume of the intake manifold. The terms R and V_m are constant. To save microprocessor execution time, this quantity can be calculated once per microprocessor loop and reused by the anticipation algorithm as K_m (k) (described below);
$\dot{M}_{EGR}(k)$	is the present estimate of the flow of EGR at the EGR orifice 47;
$\alpha_1(N(k))$	and $\alpha_2(N(k))$ are the mapped engine pumping rate coefficients which are functions of engine speed (N);
$P_{amb}(i)$	is the ambient pressure (barometric pressure);
$P_m(k)$	is the measured intake manifold pressure;
P_{amb_nom}	is the barometric or ambient temperature when the engine characterisation was performed;
$T_m(k)$	is the intake manifold gas temperature; and
$T_m(k-1)$	is the previous $T_m(k)$.

For practical sensors, $T_m(k-1)/T_m(k)$ will always be approximately 1. Microprocessor execution time can be conserved by simplifying this temperature ratio to 1.

The general expression of sample time Δt will be replaced with a more specific engine cylinder event sample time Δt_{evt}. The expression $\alpha_a(N(k)) + \alpha_2(N(k)) P_{amb}(i)/P_m(k) P_{amb\_nom}$ is worth preserving during the execution of the air charge algorithm for additional processing, as will be described in greater detail below, as:

$$\beta(k) = fn_{eng_{temp}}(T_m, T_{eng}) \left[\alpha_1(N(k)) + \alpha_2(N(k)) \frac{P_{amb}(i)}{P_m(k)\, P_{amb_{nom}}} \right]. \qquad \textbf{(11)}$$

Further, because the denominator of the P_{EGR} expression will be used several more times (for air charge anticipation described later in this disclosure), we will calculate a term d(k):

$$d(k) = \frac{1}{\Delta t_{evt} K_m(k) \beta(k) + 1} \qquad \textbf{(12)}$$

Now the expression for P_{EGR} becomes:

$$P_{EGR}(k) = d(k) \left[P_{EGR}(k-1) + \Delta t_{evt} K_m(k) \dot{M}_{EGR}(k) \right] \qquad \textbf{(13)}$$

Now that the partial pressure of EGR is determined, the partial pressure of air is determined, as shown at block 114, as follows:

$$P_{air}(k) = P_m(k) - P_{EGR}(k). \qquad \textbf{(14)}$$

Compared to the direct throttle-flow based estimate of the partial pressure of air, the advantages of indirect EGR estimate are:

- EGR rarely exceeds 15% of the total flow of gas into the cylinders. Various errors that occur in making these estimates, regardless of whether they

are transient in nature or due to shifts in flow characterisation of the EGR orifice, are reduced in overall effect. For example, at EGR flow rate equal to 15% of the total gas flow, 10% error in EGR flow estimation would effect the air/fuel ratio by only 1.3%.

- If secondary systems on the vehicle that tap into the intake manifold (brakes, canister purge, etc.) are actuated and introduce some air, the throttle flow based estimate for partial air pressure (a direct calculation of the partial pressure of air, which is an alternate method to this invention disclosure) will actually assume this extra gas is EGR, not air.

At this point, we can solve for cylinder port air flow, block 116, because we now have $P_{air}(k)$. This is done by using the engine pumping rate equation:

$$\dot{M}_{cyl_{air}}(k) = fn_{eng_{temp}}(T_m, T_{eng})\left[\alpha_1(N(k))P_{air}(k) + \alpha_2(N(k))\frac{P_{air}(k)P_{amb}(i)}{P_m(k)P_{amb_{nom}}}\right] \quad (15)$$

If required by other parts of the engine controller (spark advance scheduling, for example), the mass flow of EGR or relative percentage of EGR can be determined, as shown at block 118, according to the following:

$$\dot{M}_{cyl_{EGR}}(k) = \frac{P_{EGR}(k)}{P_{air}(k)}\dot{M}_{cyl_{air}}(k) \quad (16)$$

The flow rate of cylinder air can be integrated over a period of an air induction stroke (time of an engine event: Δt_{evt}) to calculate the cylinder air charge (mass of air inducted into a cylinder port) when this value is needed for fuel mass calculation, block 120, as follows:

$$M_{cyl_{air}} = \Delta t_{evt}\dot{M}_{cyl_{air}}(k) \quad (17)$$

where M_{cyl_air} is the present cylinder air charge.

Due to typical limits of engine controller signal processing, the M_{cyl_air} value is delayed. Furthermore, the fuel injectors require finite time to dispense fuel (the time typically being equal to the duration of one or even two engine events), so the present value of cylinder air charge during a transient condition is typically several engine events late. It is therefore necessary to predict future values of cylinder air charge, as shown at block 122. This can be done by using the last few samples of $P_{air}(k)$ and the throttle position. Throttle change creates an airflow change that in turn creates a partial air pressure change in the intake manifold. Using the predicted partial pressure of air allows one to solve for future cylinder air charge.

By taking advantage of the model based estimation developed in this disclosure, the anticipated air will be more accurately determined versus other simpler schemes that respond to rapid throttle changes and directly force fuel injector changes without regard to system conditions.

First, the next two throttle positions are estimated as follows:

$$throt\_ang(k)_{evt+1} = throt\_ang(k) + tp\_slope(k) \times \Delta t_{evt} \tag{18}$$

$$throt\_ang(k)_{evt+2} = throt\_ang(k) + 2 \times tp\_slope(k) \times \Delta t_{evt}, \tag{19}$$

where tp_slope represents the anticipated rate of change of throttle angle with respect to time. In the preferred embodiment, a straight line through the last m available measurements is used to predict the next two values of throttle angle position, whether they occur at a fixed rate or at an engine event. This can be achieved a number of ways. A preferred solution uses a least squares regression of the last four (m=4) throttle position readings to determine the rate of throttle position change. This

provides a prompt update of rate but still suppresses sensor noise. Other methods, such as filtering and then taking the derivative of the throttle position signal may work as well.

Next, the next two throttle air flow rates are estimated as follows:

$$\dot{M}_{air}(k)_{evt+1} = \frac{P_{amb}(i)}{P_{amb_{nom}}}\sqrt{\frac{T_{amb_{nom}}}{T_{amb}(k)}}$$

$$[Fn_{ThrottleFlow}(throt_{ang}(k)_{evt+1}) + Fn_{AirBypass}(dtycyc(k))] \tag{20}$$

$$x\ Fn_{SubSonic}\left(\frac{P_m(k)}{P_{amb}(i)}\right)$$

$$\dot{M}_{air}(k)_{evt+2} = \frac{P_{amb}(i)}{P_{amb_{nom}}}\sqrt{\frac{T_{amb_{nom}}}{T_{amb}(k)}}$$

$$[Fn_{ThrottleFlow}(throt_{ang}(k)_{evt+2}) + Fn_{AirBypass}(dtycyc(k))] \tag{21}$$

$$x\ Fn_{SubSonic}\left(\frac{P_m(k)}{P_{amb}(i)}\right)$$

The air bypass valve (here characterised by Fn_AirBypass(dtycyc(k)), where dtycyc(k) refers to the actuation signal to the valve is controlled by the powertrain control system. For exact representation of the transient air flow, predicted values $dtycyc(k)_{evt+1}$ and $dtycyc(k)_{evt+2}$ should be sent to the air charge estimator. For the purposes of simplicity, this disclosure will only use dtycyc(k).

The anticipated partial pressure of air will change based on the anticipated mass of air flow from the throttle body.

$$P_{air}(k)_{evt+1} = \frac{P_{air}(k) + \Delta t_{evt} \dfrac{RT_m(k)}{V_m} \dot{M}_{air}(k)_{evt+1}}{\Delta t_{evt} \dfrac{RT_m(k)}{V_m} fn_{eng_{temp}}(T_m, T_{eng}) \left(\alpha_1(N(k)) + \alpha_2(N(k)) \dfrac{P_{amb}(i)}{P_m(k) P_{amb_{nom}}} \right) + 1} \quad (22)$$

where we have decided to use the current values of $T_m(k)$, $N(k)$, and $P_m(k)$, thus the term $d(k)$ and $K_m(k)$ can be used:

$$P_{air}(k)_{evt+1} = d(k) \left[P_{air}(k) + \Delta t_{evt} K_m(k) \dot{M}_{air}(k)_{evt+1} \right] \quad (23)$$

The two PIP ahead prediction is:

$$P_{air}(k)_{evt+2} = d(k) \left[P_{air}(k)_{evt+1} + \Delta t_{evt} K_m(k) \dot{M}_{air}(k)_{evt+2} \right] \quad (24)$$

Given $P_{air}(k)_{evt+1}$ and $P_{air}(k)_{evt+2}$, we can obtain the anticipated values of air charge as:

$$M_{cyl}(k)_{,evt+1} = \Delta t_{evt} \dot{M}_{air}(k)_{evt+1} = \Delta t_{evt} \beta(k) P_{air}(k)_{evt+1} \quad (25)$$

$$M_{cyl}(k)_{,evt+1} = \Delta t_{evt} \dot{M}_{air}(k)_{evt+2} = \Delta t_{evt} \beta(k) P_{air}(k)_{evt+2} \quad (26)$$

Using the earlier $\beta(k)$ preserved term:

$$M_{cyl}(k)_{,evt+1} = \Delta t_{evt} \beta(k) P_{air}(k)_{evt+1} \quad (27)$$

$$M_{cyl}(k)_{,evt+2} = \Delta t_{evt} \beta(k) P_{air}(k)_{evt+2} \quad (28)$$

Thus, the present invention provides a system and method for estimating cylinder air flow from a lesser EGR partial pressure so as to substantially reduce estimator sensitivity to model uncertainty.

CLAIMS

1. A method for determining air flow into a cylinder of an internal combustion engine having an intake manifold for receiving air to be inducted into the engine, an exhaust manifold for emitting exhaust gas combusted by the engine and an exhaust gas recirculation (EGR) orifice for recirculating a portion of the exhaust gas into the intake manifold, the method comprising:

sensing a pressure of the intake manifold and generating a corresponding intake pressure signal;

determining a pressure of the exhaust manifold and generating a corresponding exhaust pressure signal;

determining an EGR flow through the EGR orifice based on the intake pressure signal and the exhaust pressure signal;

determining a partial pressure of air based on the EGR flow and the intake pressure signal; and

determining the air flow into the cylinder based on the partial pressure of air.

2. A method as claimed in claim 1, further comprising:

controlling the engine based on the determined air flow into the cylinder.

3. A method as claimed in claim 1, wherein determining the pressure of the exhaust manifold includes:

determining an ambient barometric pressure; and

determining a previous estimate of the air flow into the cylinder.

4. A method as claimed in claim 3, wherein determining the EGR flow further includes determining a temperature of the exhaust manifold.

5. A method as claimed in claim 4, wherein determining the temperature of the exhaust manifold includes:

determining the previous value of the air flow into the cylinder; and

determining a spark advance variable corresponding to a spark timing of the engine.

6. A method as claimed in claim 5, wherein determining the partial pressure of air includes:

determining a speed of the engine;

determining a temperature of the engine; and

determining a partial pressure of the EGR based on the EGR flow, the speed of the engine, the intake manifold pressure, and the temperature of the engine.

7. A method as claimed in claim 1, further comprising determining a mass of air inducted into the cylinder based on the determined air flow.

8. A method as claimed in claim 7, wherein the engine further includes a throttle plate for controlling the amount of air to be delivered to the engine, wherein the method further comprising:

sensing a position of the throttle plate and generating a corresponding throttle position signal;

determining a first anticipated throttle position based on the throttle position signal; and

determining a first future mass of air inducted into the cylinder for a first next cylinder event based on the partial pressure of air and the anticipated throttle position.

9. A system for determining air flow into a cylinder of an internal combustion engine having an intake manifold for receiving air to be inducted into the engine, an exhaust manifold for emitting exhaust gas combusted by the engine

and an exhaust gas recirculation (EGR) orifice for recirculating a portion of the exhaust gas into the intake manifold, the system comprising:

an intake pressure sensor for sensing a pressure of the intake manifold and generating a corresponding intake pressure signal;

means for determining a pressure of the exhaust manifold and generating a corresponding exhaust pressure signal; and

control logic operative to determine an EGR flow through the EGR orifice based on the intake pressure signal and the exhaust pressure signal, determine a partial pressure of air based on the EGR flow and the intake pressure signal, and determine the air flow into the cylinder based on the partial pressure of air.

10. A system as claimed in claim 9, wherein the control logic is further operative to control the engine based on the determined air flow into the cylinder.

11. A system as claimed in claim 9, wherein the means for determining the pressure of the exhaust manifold includes:

means for determining an ambient barometric pressure; and

the control logic for determining a previous estimate of the air flow into the cylinder.

12. A system as claimed in claim 9, wherein the means for determining the pressure of the exhaust manifold is an exhaust pressure sensor.

13. A system as claimed in claim 11, further comprising means for determining a temperature of the exhaust manifold for use in determining the EGR flow.

14. A system as claimed in claim 13, wherein the means for determining a temperature of the exhaust manifold is an exhaust temperature sensor.

15. A system as claimed in claim 13, wherein the means for determining the temperature of the exhaust manifold includes:

the control logic for determining the previous value of the air flow into the cylinder and determining a spark advance variable corresponding to a spark timing of the engine.

16. A system as claimed in claim 15, wherein the control logic, in determining the partial pressure of air, is operative to determine a speed of the engine, determine a temperature of the engine, and

determine a partial pressure of the EGR based on the EGR flow, the speed of the engine, the intake manifold pressure, and the temperature of the engine.

17. A system as claimed in claim 9, wherein the control logic is further operative to determine a mass of air inducted into the cylinder based on the determined air flow.

18. A system as claimed in claim 17, wherein the engine further includes a throttle plate for controlling the amount of air to be delivered to the engine, wherein the system further comprising:

a throttle plate sensor for sensing a position of the throttle plate and generating a corresponding throttle position signal; and

the control logic further operative to determine a first anticipated throttle position based on the throttle position signal and determine a first future mass of air inducted into the cylinder for a first next cylinder event

based on the partial pressure of air and the anticipated throttle position.

19. An article of manufacture for an automotive vehicle having an internal combustion engine having an intake manifold for receiving air to be inducted into the engine, an exhaust manifold for emitting exhaust gas combusted by the engine and an exhaust gas recirculation (EGR) orifice for recirculating a portion of the exhaust gas into the intake manifold, the vehicle further having an intake pressure sensor for sensing a pressure of the intake manifold and generating a corresponding intake pressure signal and means for determining a pressure of the exhaust manifold and generating a corresponding exhaust pressure signal, the article of manufacture comprising:

a computer storage medium having a computer program encoded therein for determining an EGR flow through the EGR orifice based on the intake pressure signal and the exhaust pressure signal, determining a partial pressure of air based on the EGR flow and the intake pressure signal, and determining the air flow into the cylinder based on the partial pressure of air.

20. An article of manufacture as claimed in claim 19, wherein the engine further includes a throttle plate for controlling the amount of air to be delivered to the engine and a throttle plate sensor for sensing a position of the throttle plate and generating a corresponding throttle position signal, wherein the computer program is further encoded therein for determining a first anticipated throttle position based on the throttle position signal and determining a first future mass of air inducted into the cylinder for a first next cylinder event based on the partial pressure of air and the anticipated throttle position.

21. A method for determining air flow into a cylinder of an internal combustion engine substantially as hereinbefore described with reference to the accompanying drawings.

22. A system for determining air flow into a cylinder of an internal combustion engine substantially as hereinbefore described with reference to the accompanying drawings.

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Application No:	GB 9900546.4	**Examiner:**	Steven Davies
Claims searched:	1-22	**Date of search:**	14 April 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): F1B-BBA, BBB ; G1N-NAAJCR

Int Cl (Ed.6): F02D

Other: Online databases: WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	US 5205260	(Assigned to HITACHI) e.g. column 5, lines 20-61)	1,9,19 at least
X	JP 010053032 A	(TOYOTA) see JAPIO abstract	1,9,19 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
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